Higgs BSM Benchmarks

Snowmass Higgs Working Group

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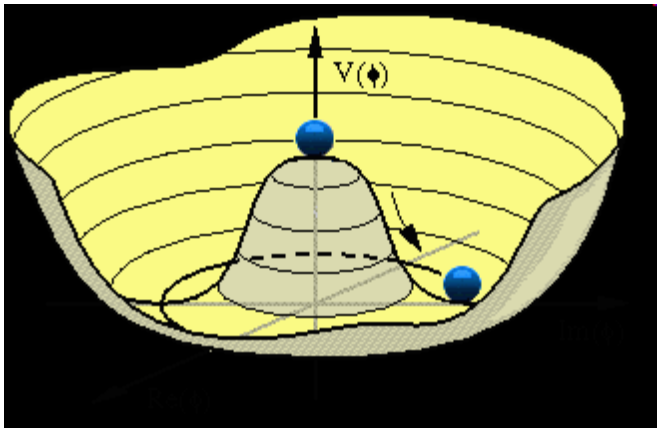


4-Prong Approach

- Look for extra Higgs particles present in many models
- Look for exotic and rare decays of Higgs
- Precision measurements of Higgs couplings
- Other precision measurements of Higgs properties, such as spin, CP admixtures, Higgs self coupling from HH production, total Higgs width, invisible width, mass

Extended Higgs Sectors

- Many models have more than one Higgs boson
- As a representative set, we will consider:
  - Models with an additional Higgs Singlet
  - Composite Higgs Models
  - 2 Higgs Doublet Models
    - MSSM and NMSSM

Also, effective Lagrangian fits to Higgs couplings, See session 4

Higgs Singlet Model

- Singlet, S, mixed with SM Higgs, H_{SM}
  - S could be hidden sector field
  - Communicates to observed sector through Higgs couplings

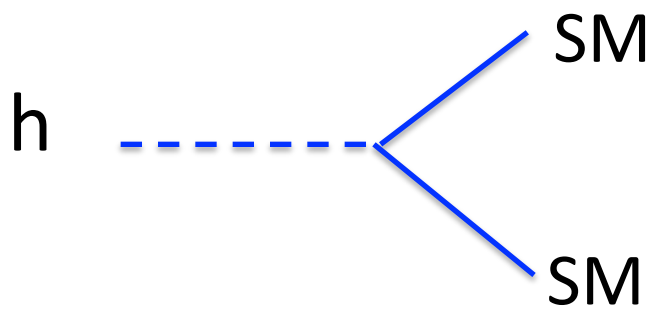
$$L_{eff} = D_\mu \Phi D^\mu \Phi^\dagger + \mid D_\mu S \mid^2 + \mu^2 \Phi\Phi^\dagger + m_S^2 \mid S \mid^2$$
$$- \lambda(\mid \Phi\Phi^\dagger \mid)^2 - \rho S^4 - \kappa(\Phi^\dagger\Phi)S^2$$

- Physical Higgs: h, H

$$h = \cos\theta_h H_{SM} + \sin\theta_h S$$
$$H = \sin\theta_h H_{SM} - \cos\theta_h S$$

Higgs Singlet Model

- Universal rescaling of Higgs couplings



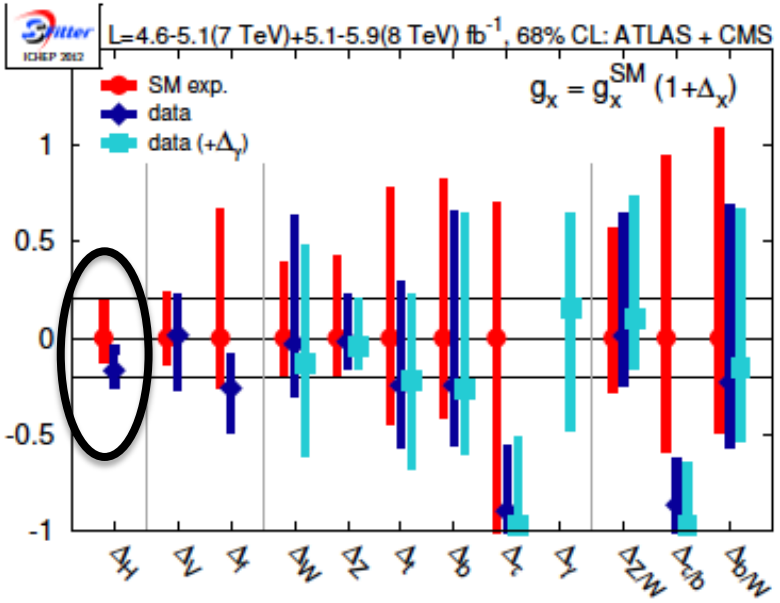
$$(1+\Delta_H) g^{SM}_{hXX}$$

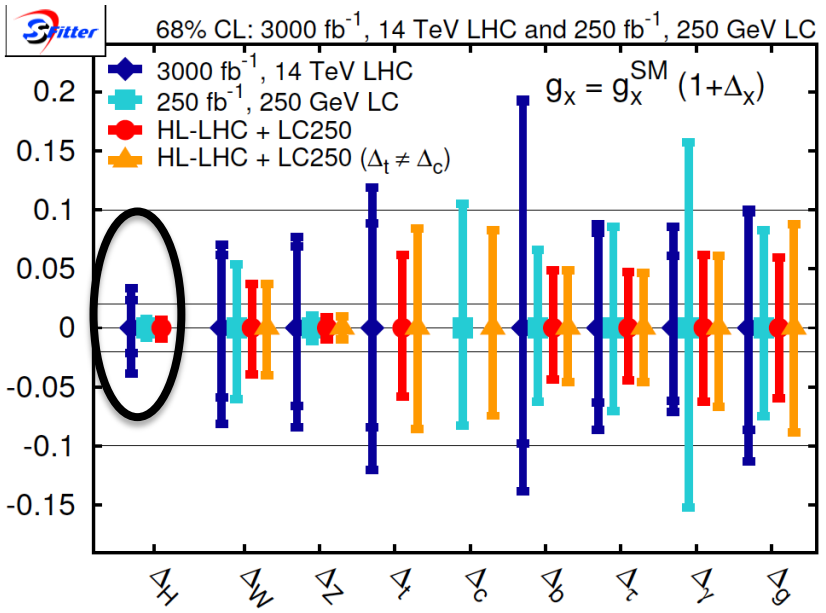
$$\frac{\Delta_H}{g^{SM}_{hXX}} \sim -\frac{\sin^2\theta_h}{2}$$

- New decays possible

$$H \to hh$$

Higgs Singlet: Present and Future





[Klute, Lafaye,Plehn, Rauch, Zerwas]

Two Higgs Doublet Models

- Parameters are α (mixing in neutral h/H sector), tan β
- $L = -g_{hii}\frac{m_i}{v}\overline{f}_i f_i h - g_{hVV}\frac{2M_V^2}{v}V_\mu V^\mu h$
- 4 possibilities for Higgs coupling assignments

	I	II	Lepton Specific	Flipped
g_{hVV}	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$	$\sin(\beta-\alpha)$
$g_{ht\bar{t}}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$
$g_{hb\bar{b}}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$
$g_{h\tau^+\tau^-}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$

Type II is MSSM – like 2 Higgs doublet model

2 Higgs Doublet Models: Plans

- Search reach for H^+,H,A at future machines
- Limits on tan β, α plane for fixed H^+, A
  - Consider both decoupling limit (heavy Higgs) and M_{H+}~300 GeV
- Include restrictions from B physics
- Higgs search reach and coupling limits in MSSM and NMSSM
  - Other (non-Higgs) particles in MSSM and NMSSM in loops can affect Higgs couplings

Composite Models

- Parameterize by effective operators

$$L_{eff} = \frac{2c_H}{f^2} \mid \Phi D_\mu \Phi^\dagger \mid^2 + \frac{c_y}{f^2}\frac{m_f}{v}\left(\Phi^\dagger \Phi \overline{\psi}_L \Phi f_R + h.c.\right)$$

- c_H, c_y predicted in specific models
- $\Delta g_{hXX} \sim v^2/f^2 = \zeta^2$

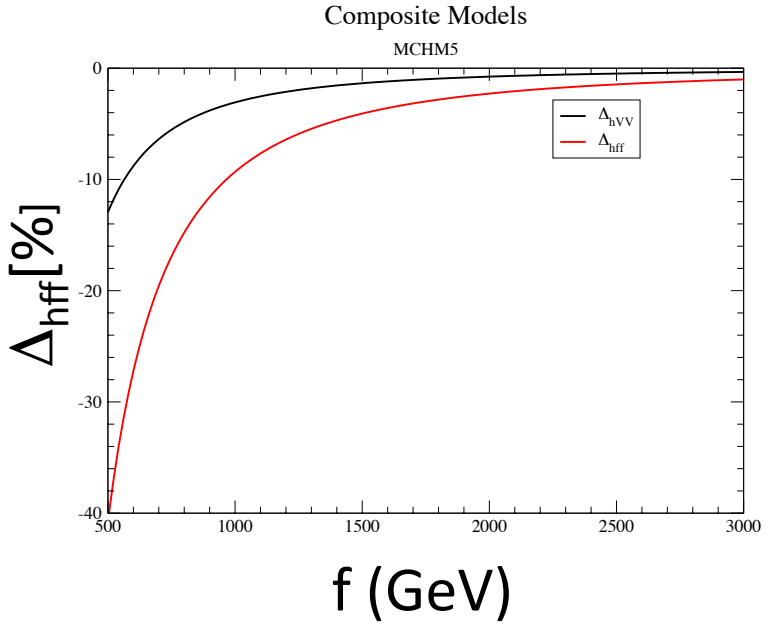
$$\Gamma(h \to f\overline{f}) = \Gamma(h \to f\overline{f})_{SM}\left(1 - \zeta(2c_y + c_H)\right) \qquad \Delta_f = -\frac{\zeta}{2}(2c_y + c_H)$$

$$\Gamma(h \to W^+W^-) = \Gamma(h \to W^+W^-)_{SM}\left(1 - \zeta c_H\right) \qquad \Delta_V = -\frac{\zeta}{2}c_H$$

- Precision electroweak measurements restrict f
- Interesting effects in 2 Higgs production due to effective vertex: $t\bar{t}hh$

Examples of Composite Models

- Models differ in high scale fermions representations
  - MCFM5: $1+\Delta_V = \sqrt{1-\zeta}, \quad 1+\Delta_f = \frac{1-2\zeta}{\sqrt{1-\zeta}}$
  - MCFM4: $1+\Delta_V = 1+\Delta_f = \sqrt{1-\zeta}$

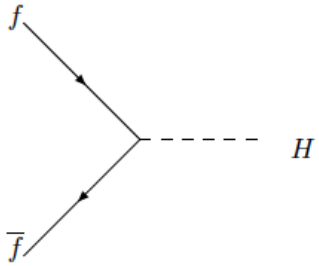


- 10% measurement of Δ_{hff} gets to 1 TeV scale
- 2% measurement gets to 2 TeV

Composite Model is Special Case

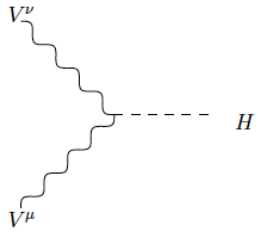
- Yukawa couplings:

$$-i\frac{m_f}{v}\left(1+\Delta_f\right)$$



- Couplings to gauge bosons:

$$-i\frac{2M_V^2}{v}\left(1+\Delta_V\right)$$



V=W,Z

- Assume $\Delta_W=\Delta_Z$?

$$\Delta T \sim (\Delta_W - \Delta_Z)$$

See Session 4

Working Group Output

- General coupling fits+ fits within specific models

	LHC300	LHC3000	ILC250	ILC500	ILC1TeV	CLIC 3 TEV	μμ
Δ_H							
Δ_V							
Δ_f							
Δ_b							
Δ_τ							
Δ_V							
…							

See recommendations of LHC Higgs Cross Section Working Group

Higgs Self-Couplings

- Need to measure hhh coupling

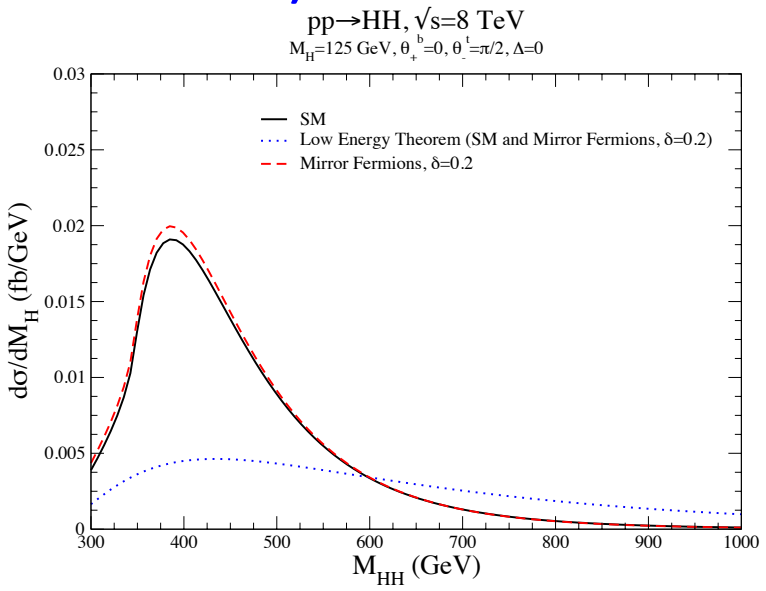
$$V = \frac{M_h^2}{2} h^2 + \frac{M_h^2}{2v} h^3 + \frac{M_h^2}{8v^2} h^4$$

- At ILC: $e^+e^- \to Zhh$
- At LHC, VBF: $W^+W^- \to hh$ and $gg \to hh$

Small rates limit sensitivity

2 Higgs Production at the LHC

- In simple models, get approximately SM rate
- Large 2 Higgs rate could be smoking gun for composite Higgs models (which have new contributions)



Require parameters to give SM single H production rate and be consistent with precision EW

[Dawson, Furlan, Lewis]

Higgs Precision Properties

- Spin/ CP admixtures

$$L \sim \overline{f}(a + b\gamma_5) f h$$

- Total Higgs width
- Invisible width
- λ_{hhh}
- Make table as above

Higgs Working Group

- Many topics to be addressed
- Please add to our collection of 1pagers

  http://quark.phy.bnl.gov/~dawson/1pagers

- (These will help us fill in gaps of what needs to be done!)
- Lots of work and we welcome volunteers
- Much information in literature….point us to it